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Greener energy: Issues and challenges for Pakistan-geothermal energy prospective

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ABSTRACT

There is an indispensable need to develop geothermal technologies to supplement the long-term energy needs of Pakistan to a significant level. Geothermal energy is one of the oldest, most versatile and also most common form of utilization of renewable energy. Pakistan is rich in geothermal energy, many of the researchers highlighted and emphasized about its importance, but due to less awareness, lack of confidence and management, no realistic work has been done so far in this domain. This paper investigates the progress of geothermal energy sources, technologies and its potential. Finally the prospects for the geothermal energy sources in Pakistan are described to encourage national and international investment in developing these resources.

Contents

1. Introduction

Geothermal energy consists of the thermal energy stored in the Earth's crust. Cataldi et al. [1] had published historical records and stories of geothermal utilization from all over the world. Geothermal energy has been exploited for power generation since 1904 when Prince Piero Ginori Conti invents the first geothermal power plant at the Larderello dry steam field in Tuscany, Italy [2,3]. The development of geothermal energy resources for utility-scale electricity production in the United States began in the 1960s. The progress in geothermal power from 1960 to 2012 is shown in Fig. 1 [4]. As of May 2012, approximately 11,224 MW of installed geothermal power capacity was online worldwide. In US the installed geothermal capacity increased from 3187 MW in early 2012 to 3386 MW in February of 2013.

US is developing additional 2511–2606 MW geothermal based electric power plants in next three years [5]. In Iceland Geothermal power facilities currently generate 25% of the country's total electricity production. In 2009, roughly 84% of primary energy use in Iceland came from indigenous renewable resources, thereof 66% was from geothermal. Almost 99% of Iceland's houses and buildings are heated by natural hot water [6]. Other principal use of geothermal energy is fermentation, heating and cooling homes and businesses, heating in industrial process, heating greenhouse, refrigeration, industrial and

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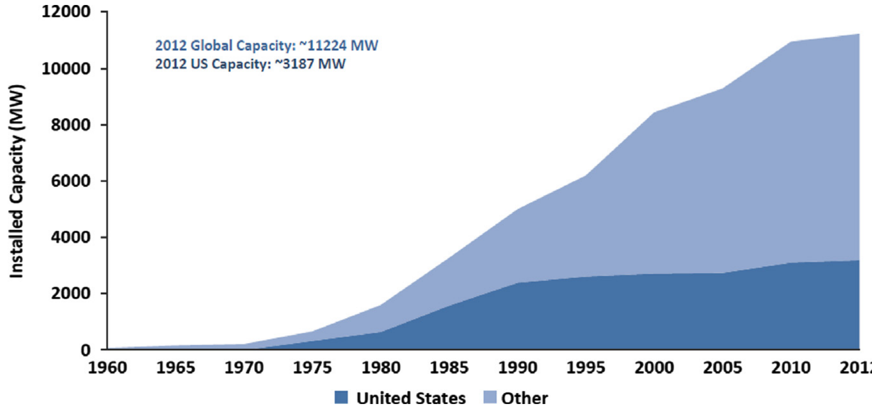

Fig. 1. US and worldwide geothermal installed capacity 1960–2012 [4].

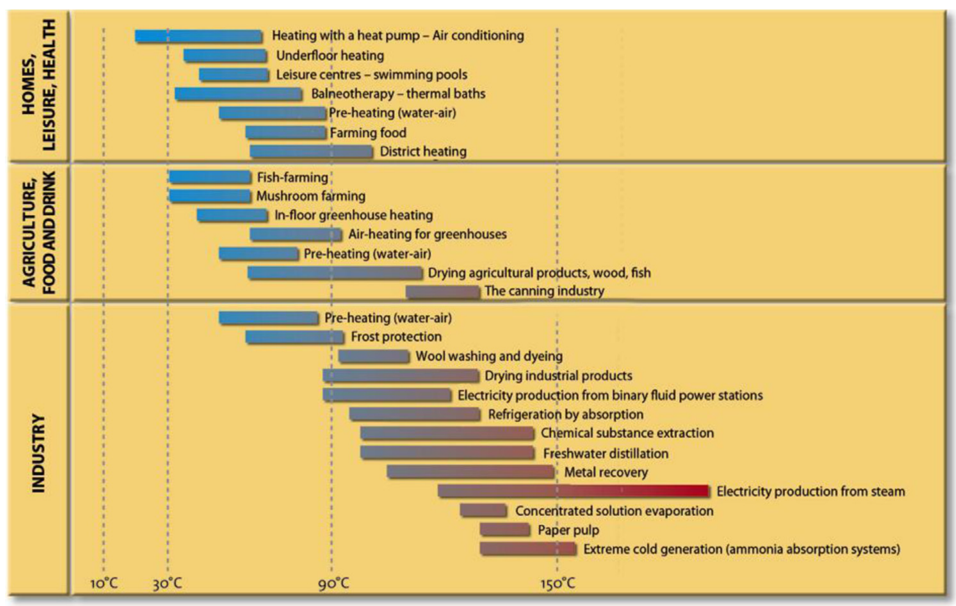

Fig. 2. Principal uses of geothermal energy with respect to temperatures [9].

crop drying, ice melting, balneological utilization, desalination and distillation [7,8] as shown in Fig. 2 [9] and Fig. 3 [10].

Geothermal energy process produces zero carbon emissions, potentially making it one of the cleanest sources of energy at our disposal. In addition, it can create a constant 24 h base-load power where other renewable energies are unable whereas solar energy can only be produced during daylight hours, and is diminished with cloud cover and wind turbines are dependent on wind speed which is inherently variable [11]. It is estimated that geothermal power plants emit only between 13 and 380 g of CO_2-equivalent per kW h of electricity. By comparison, coal-fired power plants emit about 1042 g of CO_2-equivalent per kW h of electricity, oil fired power plant 906 g of CO_2-equivalent per kW h of electricity and natural-gas-fired power plants emit about 453 g of CO_2-equivalent per kW h of electricity [12].

2. Geothermal reservoirs

The geothermal heat originates from the primordial heat generated during the Earth's formation and the heat generated by the decay of radioactive isotopes. The Earth's average heat flow is 82 milli-Watts per square centimeter (mW cm^{-2}), and the total global output is over 4×10^{13} W [3]. Thermal energy in the earth is distributed between the constituent host rock and the natural fluid that is contained in its fractures and pores at temperatures above ambient levels. These fluids are mostly water with varying amounts of dissolved salts typically, in their natural in situ state, they are present as a liquid phase but sometimes may consist of a saturated, liquid vapor mixture or superheated steam vapor phase.

The utilization of geothermal source either for power generation or for different applications depends mainly on location and temperature of resource. High temperature geothermal resources above 150 °C are generally used for power generation whereas moderate-temperature (between 90 °C and 150 °C) and low temperature (below 90 °C) resources are best suited for direct applications such as space and process heating, cooling, aquaculture, and fish farming [13]. Multipurpose utilization of high temperature geothermal resource will not only increase the efficiency of the system but will also make more cost effective [14,15].

In geothermal field the temperature of rocks increases with depth. This gradient averages 30 °C/km of depth. However, there are areas of the earth's crust which are accessible by drilling, and where the gradient is well above the average. This occurs where there is a magma bodies undergoing cooling not far from the surface (a few kilometers), but still in a fluid state or in the process of solidification, and releasing heat. In other areas, where magmatic activity does not exist, the heat accumulation is due to particular geological conditions

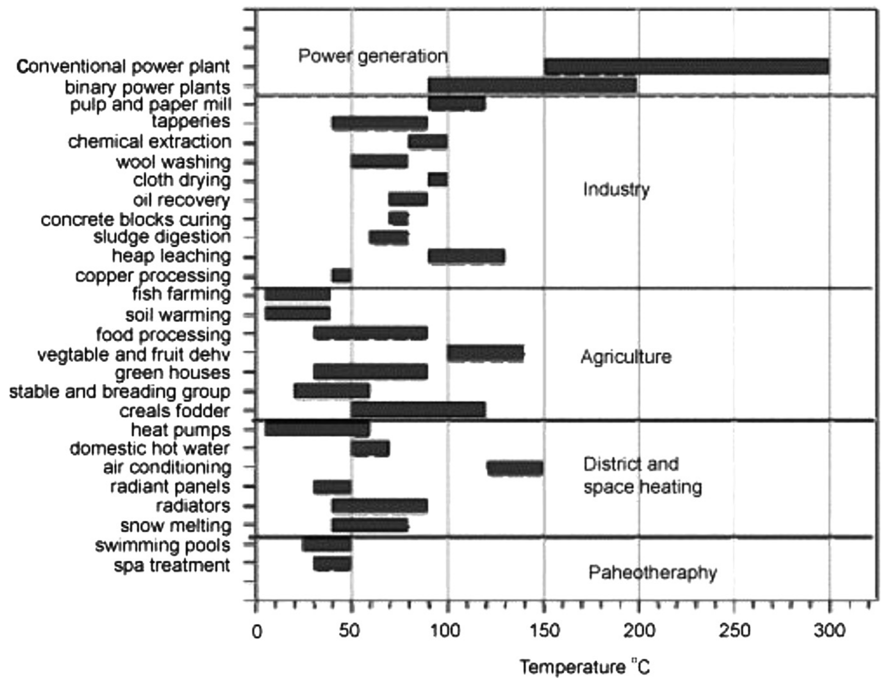

Fig. 3. Fields of application of geothermal energy according to water temperature [10].

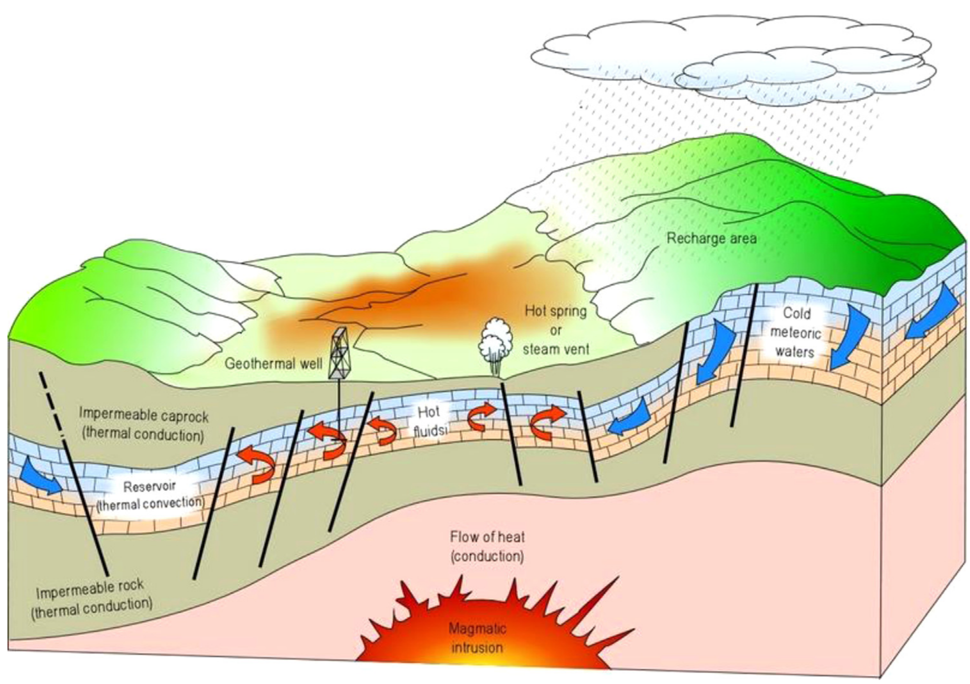

Fig. 4. Schematic representation of an ideal geothermal system. A geothermal steamfield with its elements: recharge area, impermeable cover, reservoir and heat source [17].

of the crust such that the geothermal gradient reaches anomalously high values [3,16]. To recover geothermal energy typical hydrothermal energy system comprise of the heat source, the reservoir, the recharge area and the connecting paths through which cool superficial fluid penetrates the reservoir and, in most cases, escapes back to the surface as shown in Fig. 4 [17].

Generally the heat is transferred from depth to sub-surface regions first by conduction and then by convection, with geothermal fluids acting as the carrier in this case. These fluids are essentially rainwater that has penetrated into the earth's crust from the recharge areas and has been heated on contact with the hot rocks, and has accumulated in aquifers, occasionally at high pressures and temperatures (up to above 300 °C). These aquifers are the essential parts of most geothermal fields. In most cases the impermeable rocks cover the reservoir that prevent the hot fluids from reaching the surface and keep these reservoirs under pressure.

Geothermal fields, as opposed to hydrocarbon fields, are generally systems with a continuous circulation of heat and fluid, where fluid enters the reservoir from the recharge zones and leaves through discharge areas (hot springs, wells). Viable geothermal resource must meet certain conditions. The first requirement is accessibility. This is usually achieved by drilling to depths of interest, frequently using conventional methods similar to those

Table 1
Geothermal energy technologies.

Technology	Attributes
Conventional hydrothermal	A naturally occurring geothermal system Rarely require drilling deeper than 3 km, while the technical limit for today's drilling technology is to depths greater than 10 km [19] In 2006 at Chena Hot Springs in Alaska, successful power generation occurred at a temperature of 74 °C [21]
low-temperature geothermal system	Take heat from the geothermal field at temperatures of 150 °C or less and typically used in direct-use applications Kalina or Organic Rankine Cycle (ORC) is common with lower temperature geothermal resources [2,22] Low efficiency requires increased power plant equipment size (turbine, condenser, pump and boiler) that may become cost prohibitive
Enhanced geothermal system (EGS)	It is a human developed reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS system, the natural permeability is enhanced – or created where it does not exists – through stimulation In EGS two wells are drilled. An injection well and a production well. Operation is explained in Fig. 5 [19] EGS has been successfully realized on a pilot scale in Europe and United States
Direct use	Drilling to depths of only 305 m or less is relatively inexpensive and can be used for air-conditioning or heating systems to improve their operation significantly In most domestic air-conditioning systems, the heat being removed from the house is exhausted into the outdoor air, which is, naturally, at a higher temperature than the air inside the house The operating cost of a ground heat-exchange air-conditioning system is lower than that for an air heat-exchange system, but the installation cost is higher. In both systems, heat pumps, which can either discharge heat out or draw it in, are required Fig. 6 (A and B) [23] compares systems that exchange heat with the air (Fig. 6A) or with the ground (Fig. 6B) and shows their different structures Currently, it costs about three times more to install a ground-exchange heating and cooling system than it does to install an air-exchange system

used to extract oil and gas from underground reservoirs [18]. The second requirement is sufficient reservoir productivity. For hydrothermal systems, one normally needs to have large amounts of hot, natural fluids contained in an aquifer with high natural rock permeability and porosity to ensure long-term production at economically acceptable levels [19,20]. When sufficient natural recharge to the hydrothermal system does not occur, a reinjection scheme is necessary to maintain production rates. Thermal energy is extracted from the reservoir by coupled transport processes (convective heat transfer in porous and/or fractured regions of rock and conduction through the rock itself) [18]. The heat extraction process is designed keeping in consideration the constraints imposed by prevailing in situ hydrologic, lithologic, and geologic conditions. Any waste products must be properly treated and safely disposed of to complete the process. Many aspects of geothermal heat extraction are similar to those found in the oil, gas, coal, and mining industries. Because of these similarities and equipment, techniques, and terminology borrowed or adapted from oil and gas sector for use in geothermal development that has, to some degree, accelerated the development of geothermal resources [19]. A number of resource related properties – temperature gradient, natural porosity and permeability of the rock, rock physical properties, stresses in the rock, water stored in the rock, and susceptibility to seismicity – control the rate of extraction of energy from reservoir [19]. Typically in a successful hydrothermal reservoir, a wells produce 5 MW or more of net electric power through a combination of temperature and high fluid flow rate [19]. For instance, a well in a shallow hydrothermal reservoir producing water at 150 °C need to flow at about 125 kg s^{-1} to generate about 4.7 MW of net electric power to the grid.

High flow rates are only possible if the reservoir has high transmissivity. While permeability is a property of the rock only (related to the interconnectedness and size of cracks or pores), the transmissivity, which includes the cross sectional area that the fluid flows through on its way to the well, can be influenced by well design. Measured transmissivities in geothermal systems are very high (greater than 100 D is common), compared to oil and gas reservoirs with transmissivities often around 100 mD [19]. Rocks that are critically stressed to the point where they will fail, shear, and movement during stimulation should produce fractures that will stay open and allow for fluid circulation. High transmissivity can come from a single fracture with a large aperture, or from a large number of fractures with small apertures. Both high flow rates and low pressure drop are achieved when large number of fractures with small fracture apertures gave high transmissivity [19]. Rocks with at least some connected permeability through either fractures or pore spaces are more likely to result in a connected circulation system after stimulation [19]. The fracture system should also allow injected cool water to have sufficient residence time to contact the hot rock so that reaches close to the formation temperature when it leaves from production wells. Under given flow conditions, the longer the life of the reservoir, the better the economics [19].

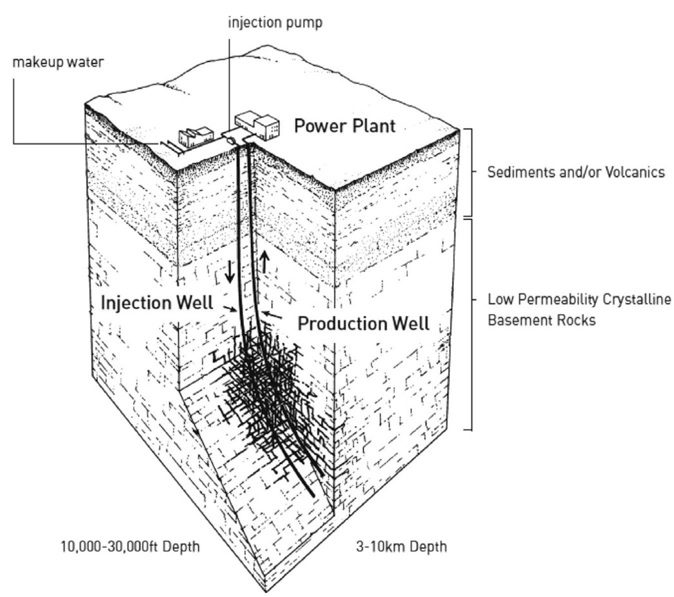

Fig. 5. Schematic of a conceptual two well Enhanced Geothermal System in hot rock in a low permeability crystalline basement formation [19].

3. Geothermal energy technologies

Geothermal energy technologies can be broken into four major categories: conventional hydrothermal, low-temperature geothermal system, Enhanced geothermal system (EGS), and direct use,

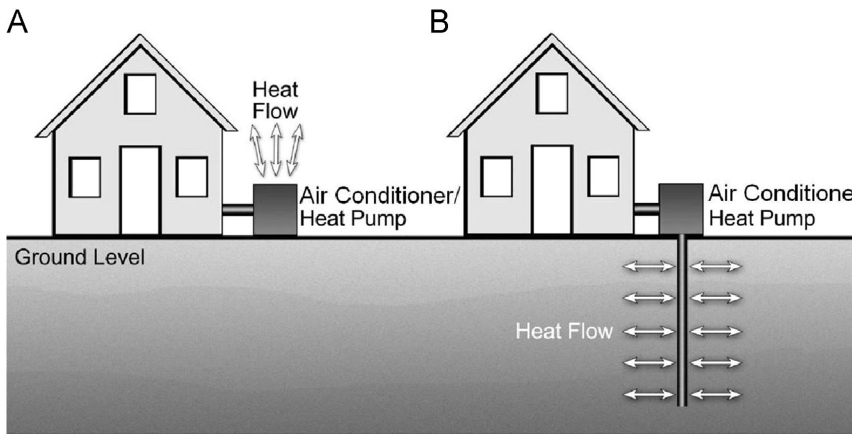

Fig. 6. (A) Schematic drawing of the heat-exchange arrangement for a heat-pump system that heats or cools using air exchange. (B) Heat-exchange arrangement for a heat-pump system that uses the ground rather than air to exchange heat [23].

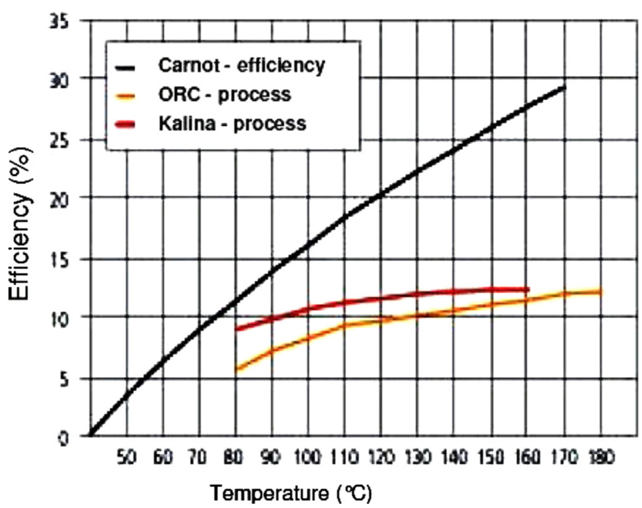

Fig. 7. Thermodynamic cycles with respect to their efficiency [26].

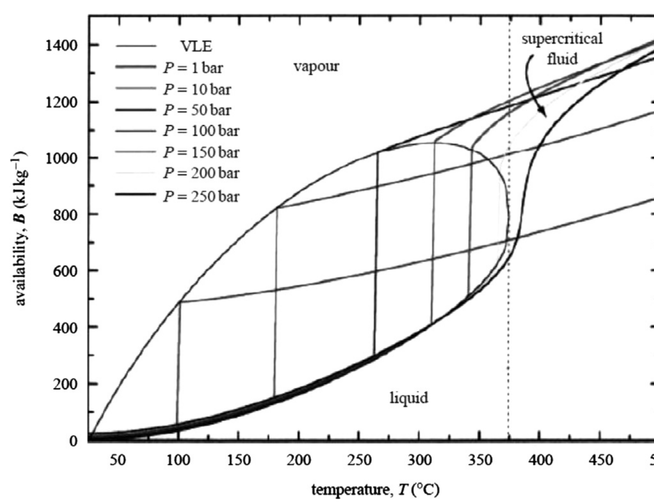

Fig. 8. Availability diagram for water. The magnitude of the availability is a direct measure of the maximum electrical work- or power-producing potential of aqueous-produced geofluid at specific-state conditions of temperature and pressure [18].

including geothermal heat pumps (GHPs). The first three categories generate electricity, while the fourth is used primarily for heating and cooling and hot water production [12]. Attributes of all four technologies are briefly examined in Table 1.

The moderate temperature heat from geothermal sources cannot be converted efficiently to electrical power by conventional power generation methods, and a large amount of moderate temperature heat is simply wasted. Various thermodynamic cycles such as the ORC, supercritical Rankine cycle, Kalina cycle, Goswami cycle, and trilateral flash cycle have been proposed and studied for the conversion of low-grade heat sources into electricity. Second law assessment by DiPippo [24] suggests that the difference in performance between Rankine cycles and Kalina cycle is only 3% in favor of Kalina cycle. However, the ORC is much less complex and need less maintenance [25]. The ORC applies the principle of the steam Rankine cycle, but uses organic working fluids with low boiling points to recover heat from lower temperature heat sources. The cycle is configured with an expansion turbine, a condenser, a pump, a boiler and a superheater, provided that superheat is needed.

The Kalina cycle is a new concept in heat recovery and power generation. The cycle uses a mixture of water and ammonia as working fluid. The ratio between these components is varied in different parts of the system to increase thermodynamic reversibility and therefore increases overall thermodynamic efficiency. The Kalina cycle was invented for the use of low temperature sources, like geothermal heat sources, therefore it is optimized for temperature levels below 170 °C where it has a certain efficiency advantage over other systems (refer to Fig. 7) [26]. The main reason for the improvement is that unlike steam the boiling of ammonia–water mixture occurs over a range of temperatures to hence the amount of energy recovered from the gas stream. Likewise condensation of ammonia–water also occurs over a range of temperatures and hence permits additional heat recovery in the condensation system, unlike Rankaine cycle where the low end temperature limit the condenser back pressure and power output of system. With temperatures above 170 °C, modern ORC-systems have the same or even higher efficiency compared to Kalina-systems (refer also to Fig. 7). At temperature levels above 350 °C, Rankine cycle has a clear advantage over ORC and Kalina-systems.

There are inherent limitations on converting geothermal energy to electricity, owing to the lower temperature of geothermal fluids. Lower energy source temperatures result in lower maximum work-producing potential in terms of the fluid's availability or exergy and in lower heat-to-power efficiencies as a consequence of the second law of thermodynamics. The magnitude of the availability determines the maximum amount of electrical power that could be produced for a given flow rate of

Table 2
Technologies to produce electricity from geothermal reservoirs.

Technology	Description	Figure
Dry steam plants	Dry steam power plants use high temperature, vapour-dominant, hydrothermal reservoirs The key components of such a system include the steam turbine–generator, condenser, cooling towers, and some smaller facilities for degassing and removal of entrained solids and for pollution control of some of the non-condensable gases Because of the quality of the resource and the simplicity of the necessary equipment, direct steam conversion is the most efficient type of geothermal electric power generation	Fig. 9 [28]
Flash steam plants	Flash steam power plants are used when a liquid-dominant mixture is produced at the wellhead of the hydrothermal reservoir and the temperature of the geothermal fluid is greater than about 180 °C In addition to the key components used in direct steam conversion plants flashed steam plants include a component called a separator or flash vessel The exergetic efficiencies of a single-flash and double flash cycle are 38.7% and 49%, respectively, based on 250 °C resource water temperature and 40 °C sink temperature [29,30]	Fig. 10 [28]
Binary cycle power plants	For lower-quality geothermal resource temperatures—usually below about 175 °C—flash power conversion is not efficient enough to be cost effective. In such situations, it becomes more efficient to employ a binary cycle In the binary cycle, heat is transferred from the geothermal fluid to a volatile working fluid (usually a hydrocarbon such as isobutane or isopentane) that vaporizes and is passed through a turbine These power plants generally have higher equipment costs than flash plants because the system is more complex Since all the geothermal brine is re-injected into the aquifer, binary cycle plants do not require mitigation of gaseous emissions and reservoir fluid volume is also maintained	Fig. 11 [28]

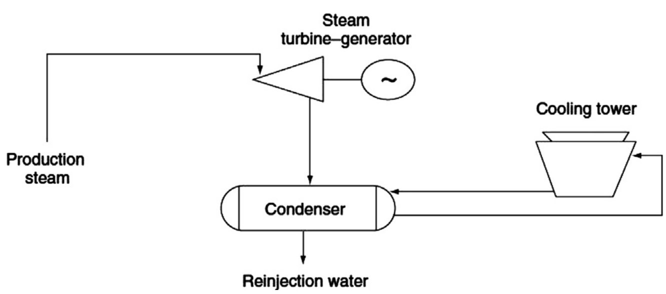

Fig. 9. Direct steam conversion [28].

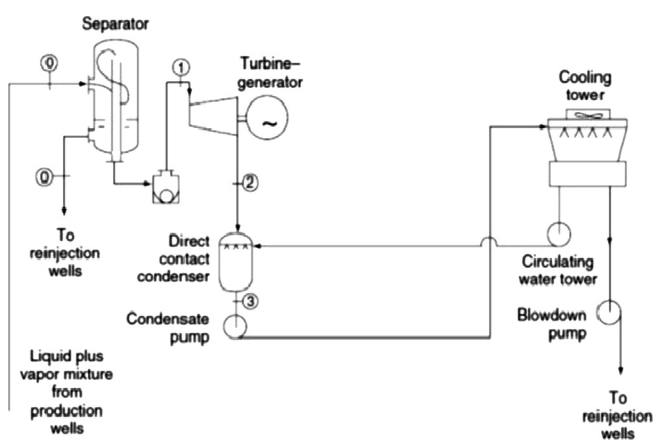

Fig. 10. Flashed steam conversion [28].

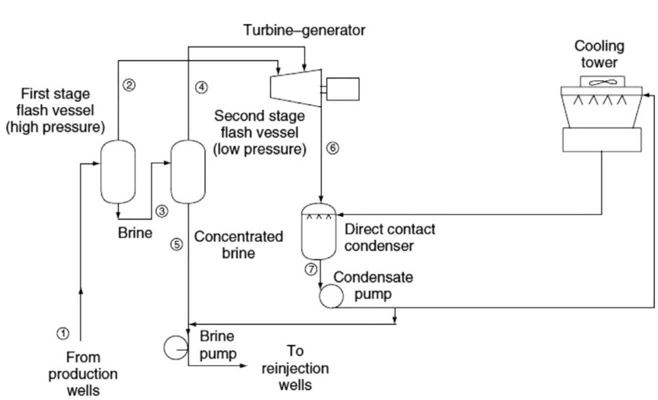

Fig. 11. Binary cycle conversion [28].

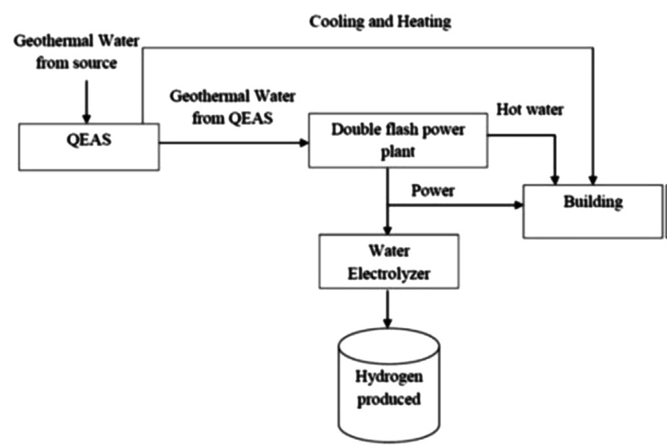

Fig. 12. Schematic diagram of the integrated system [14].

produced geofluid, given a specified temperature and density or pressure. Fig. 8 [18] shows how the availability of the geofluid (taken as pure water) varies as a function of temperature and pressure. It shows that increasing pressure and increasing temperature have a nonlinear effect on the maximum work-producing potential. For example, an aqueous geofluid at supercritical conditions with a temperature of 400 °C and pressure of 250 bar has more than five times the power-producing potential than a hydrothermal liquid water geofluid at 225 °C. Ultimately, this performance enhancement provides an incentive for developing supercritical EGS reservoirs.

4. Technologies to produce electricity from geothermal reservoirs

There are three main technologies to produce electricity from geothermal reservoirs. These well-established technologies are dry steam, flash and binary plants [27]. They are described in Table 2.

Geothermal energy based multi-generation systems enhance the efficiency, reduce the cost and environment impact and increase the sustainability [31]. Geothermal energy could avoid up to 16% of the work consumption for electrolysis and 2% for liquefaction [32]. Electrolysis even though it is one of the more energy intensive processes for producing hydrogen provides a pathway for producing hydrogen from carbon free renewable energy. Hydrogen provides the connecting point between

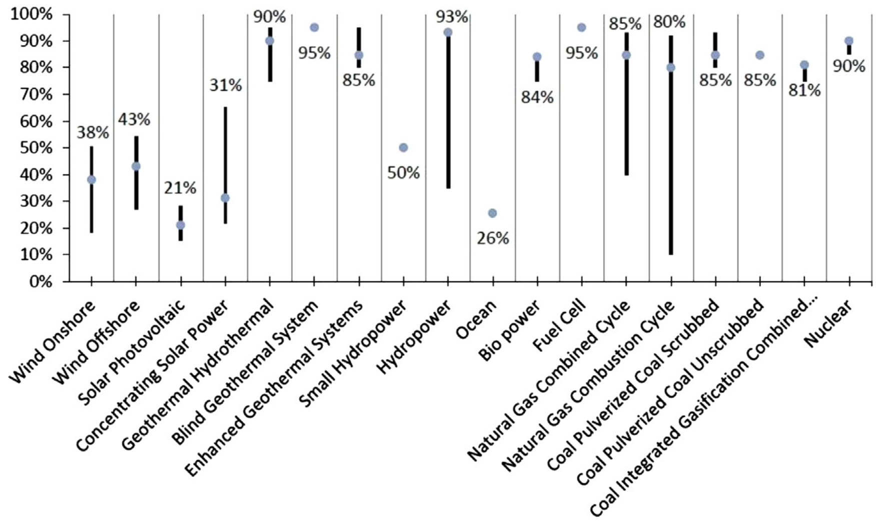

Fig. 13. Capacity factors for assorted energy sources. Blue dots represent estimate for the average capacity factor of each technology [5]. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

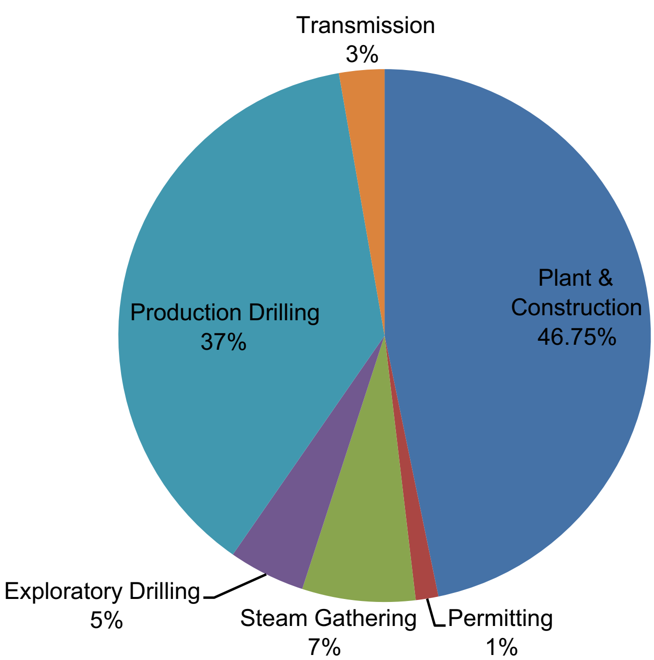

Fig. 14. Estimated developmental costs for a typical 50 MWe geothermal power plant [2].

renewable electricity production and transportation, stationary and portable energy needs. When the electricity from solar photovoltaics, wind, geothermal, ocean and hydro technologies is used to produce and store hydrogen, the renewable source becomes more valuable and diversify, especially for suitable applications [33]. Ratlamwala et al. [14] investigated geothermal double flash power plant integrated with quadruple effect absorption systems and water electrolyzer as shown in Fig. 12 from energy and exergy point of view. The study shows that the multigeneration systems utilizing renewable energy sources make the system more efficient and effective. Increasing geothermal source temperature, pressure and mass flow rate results in increasing power and rate of hydrogen produced. The amount of hydrogen produced is found to be increasing from 1.85 kg day^{-1} to 11.67 kg day^{-1} with rise in geothermal source temperature from 170 °C to 230 °C, respectively, and from 7.9 kg day^{-1} to 9.6 kg day^{-1} with increase in geothermal source pressure from 3000 kPa to 5000 kPa, respectively. However, increase in geothermal source temperature, pressure, and mass flow rate has negative effects on cooling production. Moreover, a rise in ambient temperature results in better exergetic efficiency of the system.

The capacity factor of a power plant is the ratio of its actual output over a period of time to its potential output if it were possible for it to operate continuously at full capacity. Fig. 13 [5] provides national capacity factor information for assorted energy sources which demonstrates that geothermal plants have higher capacity factors than most other renewables and even higher capacity factors than coal or natural gas.

The development of geothermal energy requires the consideration and evaluation of a number of factors, such as site (geography), geology, reservoir size, geothermal temperature, and plant type. In 2008, New Energy Finance published a breakdown of estimated costs for each developmental stage (see Fig. 14) [2]. The majority of the overall cost is typically attributed to construction of the power plant, due to the high cost of raw materials including steel. The second highest cost intensive processes are the exploratory and production drilling stages, which together comprise 42.1% of the total cost.

Using the average consumer price index Chamorro et al. [34] obtain a capital cost ranging from 1375 to 3600 \$ kW^{-1}. Regarding surface costs, it is reasonable to assume that the unit capital cost declines exponentially with increasing plant capacity as a result of economy of scale, and that the unit capital cost also depends on the technology employed, increasing with the complexity of the technology used.

Conventional hydrothermal plants typically cost \$3000 to \$4000 per installed kW. Low-temperature reservoirs typically use binary power plants, while moderate- to high-temperature reservoirs employ dry steam or flash steam plants, based on whether the production wells produce primarily steam or water, respectively. The primary stages of the geothermal development cycle are exploration, resource confirmation, drilling and reservoir development, plant construction and power production. Though geothermal projects vary widely in terms of technical elements, location, economic and political environments, financial models employed are relatively consistent. The greatest risk is associated with the initial stages of development, prior to the verification of the geothermal resource. Activities such as the drilling of

exploratory wells may prove unsuccessful even if geological data are favorable. Additionally, cost and risk increase proportionately with drilling depth. As the project moves toward the production phase, this risk begins to decline and financing options are more readily available.

Like with oil, the most expensive part of geothermal electricity generation is the drilling. Drilling a typical well doublet to produce 4.5 MW of electricity may cost $10 million. In total, electrical plant construction and doublet well drilling could cost $3–8 million per MW of electrical capacity. As for running costs, most of the energy costs for coal, gas, and renewables are in the range of $0.03–0.09 kW h^{-1} with nuclear energy toward the low end of the scale and wind and solar costing out at the high end. EGS have an average cost of about $0.06 kW h^{-1}. Geothermal power has also advantage that it is very scalable. A small plant might cost-effectively supply all the electricity needed to power a rural village, while nuclear and coal generation plants are only economical in larger-scale facilities producing 1000 MW or more. For medium sized plants (around 50 MW), levelized costs of generation are typically between US $0.04 and 0.10 kW h^{-1}, offering the potential for an economically attractive power operation [35].

5. Geothermal energy resources in Pakistan

Energy needs of Pakistan are indelibly linked to its economic and sustainable growth capabilities. Pakistan is today beset with serious energy supply difficulties due to rapid increase in demand, poor endowment of energy resources, high costs of energy imports, expanding industrialization and high population growth rate [36–38]. The heavy population growth has resulted in increased demand for housing and electricity. The rural sector, which comprises 62% of the total population, is dependent on the use of non-commercial energy resources. The infrastructure of industry, agriculture, transport, roads and the construction of buildings needs to be improved and requires a supply of energy to accelerate the development process [39]. Pakistan has been in increasing in demand across the various areas of energy sources. With a growing economy and the desire for vast production and consumption across the country, the energy demands remain high. With energy shortages as a main challenge, the government is working tirelessly to resolved problem. Pakistan has been experiencing shortage of electricity for the last several years. This shortage is prominent during summer season resulting in frequent power shutdown. Power is mainly generated by hydroelectric stations on rivers and thermal power plants (oil/gas fired) with some contribution of nuclear energy. Due to shortage of power supply the inhabitants of remote and under development areas are facing prolonged load shedding of electricity.

There are many geothermal springs in some areas having varying degree of temperature (including boiling water emanations) with significant flow-rate. If the geothermal fields have potential for power generation, this cheap source could be exploited to meet the local demands. In case of low potential the hot water can be used for warming of houses and green houses to grow vegetables especially in very cold winters [40].

Most of the high enthalpy geothermal resources of the world are within the seismic belts associated with zones of crustal weakness like the seismo-tectonic belt that passes through Pakistan having inherited a long geological history of geotectonic events. Study of the geotectonic framework by Zaigham et al. [41] suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is strengthened by (a) the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, (b) the presence of a fairly large number of hot springs in different parts of the country, and (c) the indications of Quaternary volcanism associated with the Chagai arc extending into Iran and Afghanistan border areas.

Fig. 15. Map showing areas of geothermal activity and some important geological and tectonic features of Pakistan [43].

These manifestations of geothermal energy are found within three geotectonic or geothermal environments, i.e., (i) geo-pressurized systems related to basin subsidence, (ii) seismo-tectonic or suture-related systems, and (iii) systems related to Neogene–Quaternary volcanism.

The presence of high earth-skin temperature gradient trends derived from satellite temperature data and the high geothermal gradient anomalous zone derived from scanty data of bottom-hole temperatures of some of the oil and gas exploratory wells, indicates encouraging prospects for Hot dry rock energy sources in southern Indus and Thar Desert regions inclusive of Karachi synclinorium area [42].

In Pakistan the geothermal areas have been identified in three areas the Himalayan collision zone, the Chaghi volcanic arc, and the Indus basin margin (Fig. 15) [43]. In Himalayan collision zone hot water with temperatures above 90 °C is found on the surface. In the southernmost region of the foredeep, an abnormally high thermal gradient of 4.1 °C/100 m is encountered in the Giandari oil and gas well. Likewise, the neighboring oil and gas wells at Sui and at Mart have also recorded higher than normal geothermal gradients of about 3.0–3.49 °C/l00 m. Farther northward the well at Dhodak has similar thermal gradient. In this region, thermal springs have been recorded at Uch, GarmAb at the foot of Mari Hills, ZindaPir, Taunsa and Bakkur. In the south-Kirthar geothermal zone, the oil and gas wells drilled at Lakhra show thermal gradients above normal (3.3 °C/100 m). Farther southward the oil and gas wells at Sari and Karachi revealed a geothermal gradient of about 3 °C/l00 m. In Karachi, two hot springs exist one at ManghoPir and one at Karsaz. The geological setting of the south-Kirthar geothermal zone is similar to that of the south-Sulaiman geothermal zone. The Kirthar zone also includes, a depression containing a pile of sediments 6–10 km thick. The basement beneath the depression shows prevalence of higher compression causing by the anticlockwise rotational component of the Indo-Pakistan continental plate. The region is seismically active and epicenters of shallow earthquakes ranging in magnitude from 3 to 5 on Richtcr scale have been recorded.

A development which has great potential is the direct use of the heat from shallow ground two or more meters deep which the earth maintains at a constant temperature of about 10–16 °C. A geothermal heat pump can tap into this resource to heat and cool buildings.

In the future these geothermal resources may be able to provide supplementary energy in selected areas. In Pakistan, virtually no worthwhile effort has been made to exploit this vast reserve of free energy which is cost-effective, reliable, sustainable and environment-friendly. Also, no incentives have been announced to attract investment in this form of energy so as to provide attraction to private parties to explore and exploit this sector.

6. Discussion

In Pakistan alternate energy development board (AEDB) is responsible to assist and facilitate development and generation of renewable energy to achieve sustainable growth. AEDB is also responsible for transfer of technology for development of an indigenous technology base. The AEDB is also responsible to conduct feasibility studies and surveys to identify the opportunities for power generation and other applications of renewable energy resources. Government of Pakistan has set target of achieving 5% share of power generation through renewable energies by year 2030. AEDB has initiated different demonstration projects of alternative energy technologies with the help of private entrepreneurs.

So far, geothermal power generation has not been realized in Pakistan. One of the main constraints on geothermal project development is the lack of data of potential geothermal energy resource. Zaigham et al. [41] have provided the geographical details of Hot Springs in Pakistan. Likewise Zaighama and Nayyar [42] have identified the hot dry rock geothermal energy source and its potential in Pakistan. Still no breakthrough is expected. Rather there is a need for initiate projects for resource definition and development accurate and reliable information of potential geothermal energy resource. These projects should cover technical, economic, environmental as well as social aspects along with the integrative considered. Such projects are paramount for the sustainable use of geothermal energy [44]. Usable areas could be those with naturally occurring hot springs, or those with a high temperature gradient. Country can adopt geothermal heat pumps to take care of heating needs of remote areas in coldest regions of the country which faces difficult time providing fuel for heating and cooking during winter.

In United State, Southern Methodist University (SMU) Geothermal Laboratory is regarded as one of the centers of excellence for geothermal mapping, primarily to describe heat flow, temperature-at-depth, and geothermal resource potential. National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy using data provided by the Southern Methodist University Geothermal Laboratory and NREL analyses for regions has

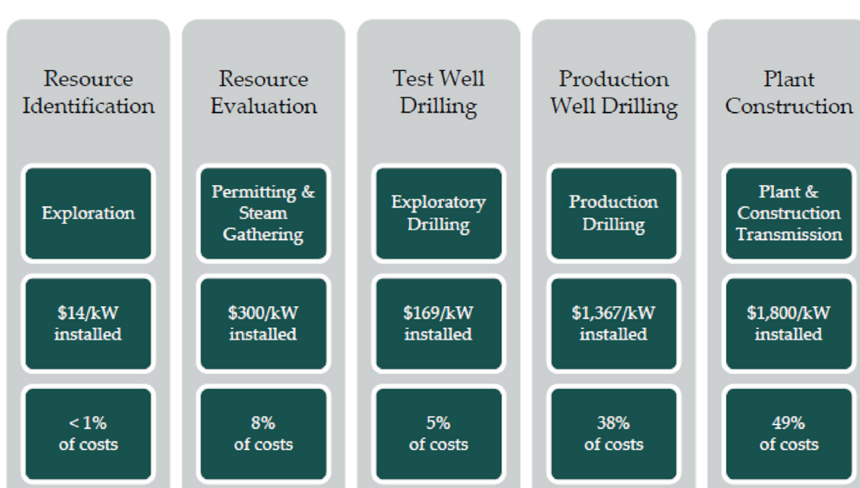

Fig. 16. Phases between exploration of potential resources and construction of a power plant [47].

Table 3
Institutes in Pakistan teaching geology.

Department	University	Year of establishment of Department	Program being offered currently
Institute of Geology	University of the Punjab, Lahore, Pakistan	1951	BS Applied Geology (4 years Annual System) M.Phil. Leading to Ph.D. Applied Geology M.Phil. Geomatics M.Sc. Seismology
Department of Geology	Karachi University, Karachi, Pakistan	1954	B.Sc. (Honors) Masters M.S./Ph.D.
Centre for Pure and Applied Geology	University of Sindh, Jamshoro-Sindh, Pakistan	1956	B.S. Geology (4 Year) M.Phil. Ph.D. program
Department of Geology	University of Peshawar, Peshawar, Khyber Pakhtunkhawa, Pakistan	1959	BS (4 years), M.S./M.Phil. and Ph.D. degree programs
Department of Geology	University of Balochistan, Quetta, Pakistan	1971	B.S. 4-years program in geology M.Sc.
Institute of Geology	The University of Azad Jammu & Kashmir, Muzaffarabad	1973	B.S. Applied Geology (4-year course) M.Phil. and Ph.D. programmes
The Department of Earth Sciences	Quaid-i-Azam University Islamabad, Pakistan	1973	M.Sc., M.Phil. and Ph.D. in Geophysics
National Centre of Excellence in Geology, University of Peshawar	University of Peshawar, Peshawar-Khyber Pakhtunkhawa, Pakistan	1974	M.Phil. Ph.D.

developed map of geothermal resource which has identified the locations of hydrothermal sites and favourability of deep enhanced geothermal systems (EGS). The U.S. Department of Energy (DOE)'s Geothermal Technologies Office currently funds 154 research and development projects leveraging nearly \$500 million in total combined investment [22]. Each project represents a growing technology sector in conventional hydrothermal, low temperature and co-produced, or Enhanced Geothermal Systems (EGS) technologies, as well as technical and non-technical research and analysis.

Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (2008) provide a common framework for categorizing geothermal resources and reserves for the information of potential investors [11]. Federal Institute for Geosciences and Natural Resources (BGR) also supports developing countries by initiating or improving the use of geothermal energy.

Turkish Mineral Research and Exploration Institute (MTA) in 1960s started the geothermal researches and investigations in Turkey. They have discovered 170 geothermal fields. Turkey's first commercial geothermal power plant located at Denizli–Kizildere field was installed in 1984 with a capacity of 20.4 MW. Turkey has 827 MW district heating and 402 MW balneological utilization capacities [45]. In addition to this 207 geothermal heat pumps have been installed in the country to date, representing a total capacity of 3 MW [46].

Even after identification of geothermal energy resources there are several phases between exploration of potential resources and construction of a power plant. Fig. 16 [47] shows the estimated development costs for a typical geothermal power plant. As shown in Fig. 16, the upfront activities of resource identification, resource evaluation, and test well drilling account for approximately 13% of the overall cost; these costs are nonetheless significant because they are risky activities (i.e., subject to dry holes) and, as a result, have high financing costs. The remainder of the capital investment (87%) comes in the later phases of drilling and construction. Marketing measures and the full involvement of all stakeholders and end users have been identified as important strategies to increase awareness and effectively push less experienced regions to invest in such green-economy [48]. Analysis by Zhou et al. [49] suggests that a hybrid solar–geothermal plant has great potentials with notable economic benefits.

In Pakistan, fortunately few oldest institutes of country are teaching geology in Pakistan. Details are given in Table 3.

However, a structure at the institutional level to ensure a higher level of coordination and cooperation within and between institutions, agencies, institutes, and other Stakeholders is missing. Also, keeping in view the lack of technical expertise and availability of fund, the best option for research institutions in Pakistan is to initiate joint projects on geothermal energy resources assessment in country with collaboration of NREL, SMU and similar agencies in developed world to benefit from their expertise and to prepare the human resource in this field. A geothermal power project is capital intensive like a hydropower project—but with a low running cost. Geothermal project is commercially viable only if it creates a positive net present value (NPV) over its economic life for the investors [45]. There is a considerable potential for geothermal energy installation in Pakistan that may be used for residential, institutional and commercial applications. Furthermore, focus should be placed on a study of a multi-energy (e.g. the geothermal energy, the solar energy, and the sewage source heat pump) heating system. Pakistan should gear the funds to support geothermal projects. These initiatives will also help government in preparing the policy regarding the promotion of geothermal energy development in Pakistan and facilitate investment in geothermal projects in the Pakistan. Country should prepare roadmap for strengthening of civil and electrical infrastructure at geothermal locations as a matter of priority. With the economic development the environment should also be paid more attention [50] for which both the political support and suitable electricity market framework conditions for the development of small-scale deep geothermal power production are very important [51]. The energy structures also influence the relationship between energy efficiency and carbon emissions [52].

7. Conclusion

World over the focus on the value of indigenous energy supplies underscores the need for re-evaluating all alternatives, particularly those that are large and well distributed nationally. Geothermal energy has long been used to extract energy in numerous countries. In recent years, an increase in installed capacity has been observed and this increase is expected to be

much greater in a near future. As geothermal energy production and use become more prominent in today's renewable energy landscape, academic institutions are taking note. Nevertheless more exhaustive studies of thermodynamic cycles and thermodynamic optimization are required to improve the exergy efficiency and overcome the inherent limitations on converting geothermal energy to electricity, owing to the lower temperature of geothermal fluids. Advanced exergy-based method is one of the best ways to optimize these systems [53]. In parallel a comprehensive assessment of enhanced, or engineered, geothermal systems should be carried out by the governments to evaluate the potential of geothermal energy becoming a major energy source. Three main components should be considered in the analysis [20]:

- Resource: estimating the magnitude and distribution of the geothermal resource.
- Technology: establishing requirements for the production from geothermal reservoirs including drilling, reservoir design and stimulation, and thermal energy conversion to electricity.
- Economics: estimating costs for geothermal supplied electricity on a national scale using newly developed methods for mining heat from the earth.

Since Pakistan is an energy-deficient country, indigenous energy sources of Pakistan are strategically important. Although proven benefits on social aspects and macro level are associated with local geothermal energy production, the future supply of geothermal energy depends on energy prices and technical progress, both of which are driven by energy policy priorities. With efficient use of geothermal energy resources Pakistan can meet a variety of energy needs, including generating electricity, providing power to agricultural sector, heating homes, facilities and pools in winter and providing process heat for food storage and agro industrial facilities in remote areas which faces fuel shortage during winter. However, there is an urgent need to initiate projects for resource definition and development of accurate and reliable geothermal energy resource map of country. Projects can be carried out in collaboration with different centers of excellence established in advanced countries for geothermal energy mapping, primarily to describe heat flow, temperature-at-depth, and geothermal resource potential. These projects should also cover technical, economic, environmental as well as social aspects along with the integrative considered. Such projects will not only create awareness but also progressively reduce the uncertainty associated with resource productivity. There is still a need for serious and extensive research to promote the renewable energy technologies, training and mutual work of geologists and engineers. The shift in the energy mix also requires much more investment in infrastructure, equipment and in R&D in case of geothermal energy resource development in Pakistan.

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